Satellite coverage in urban areas using Unmanned Airborne Vehicles (UAVs)

C. E. Palazzi[1,3], C. Roseti[2], M. Luglio[2], M. Gerla[1], M. Y. Sanadidi[1], and J. Stepanek[1]

(1) Computer Science Department, University of California Los Angeles
Boelter Hall, Los Angeles CA, 90095 USA
(2) Dipartimento di Ingegneria Elettronica, Università di Roma Tor Vergata
Via del Politecnico 1, 00133 Rome, Italy
(3) Dipartimento di Scienze dell'Informazione, Università di Bologna
Via Mura Anteo Zamboni 7, 40127 Bologna, Italy

Abstract

In case of emergency, when fixed infrastructures collapse, access to satellite resources might represent the only means of communication, even though, especially in an urban environment, shadowing can strongly reduce the visibility time. In addition, TCP based applications suffer from well know problems due to long latency. To improve performance we can act both at the architectural and protocol level.

This paper considers an innovative architecture using HAPS/UAV connected to the satellite thereby reducing the impairment of shadowing and introducing a short-range link with the user terminal; efficient TCP solutions allow use of standard equipment and applications without sacrificing performance. The combined use of both can greatly improve overall performance.

The paper investigates how this innovative system architecture can be usefully employed in critical scenarios and provides a performance evaluation of TCP based applications using high data rate links.

Keywords: HAPS, UAV, TCP, Satellite, Splitting

Acronyms

ABSE: Adaptive Bandwidth Share Estimation
HAPS: High Altitude Platforms Station
TCP: Transmission Control Protocol
UAV: Unmanned Airborne Vehicles

1 Introduction

To provide telecommunication services in emergency situations, when terrestrial infrastructures might fail, represents a critical issue. The satellite, due to its intrinsic reliability and robustness with respect to both natural disasters (earthquakes, storms, etc.) and terrorist attack or wars and due to its intrinsic ability to cover large areas is the ideal system to ensure access, and, if needed, also significant bandwidth. Moreover, while the concept of using unmanned objects [1][2] flying (HAPS/UAV) or stationary (Sky Station) at relatively low altitudes to provide backup or support capacity to high traffic areas (hot spots) has been previously introduced, it can be usefully extended to emergency situations as well. The two systems can be jointly used with the latter collecting information at high rates from user terminals thanks to the very short range and high elevation angles achievable even in urban areas, while the former provides interconnection with the terrestrial infrastructure, thus allowing the users to exchange information with the a headquarter located in some remote site.

In this paper we focus upon the performance of some conventional protocols developed for Hot Spot environments when used in this rather unconventional environment. In fact, with the HAPS/UAV + Satellite connection we expect much higher loss rates on the ground to HAPS/UAV link than in conventional Hot Spots because of distance, obstacles and HAPS/UAV motion. To characterize such a scenario classical channel models, developed for satellite environments, can be suitably applied [3][4]. The exploitation of path diversity, both at theoretical and at simulation level, has also been investigated. The relative channel models [5][6][7][8][9] are suitable for more complex scenario involving multiple HAPS/UAVs. Moreover, the satellite link has a large propagation delay and may introduce random loss of its own. Since much of the applications (e.g., web traffic, area maps, image files, emergency reports, etc.) will run on TCP, it will be important to evaluate the performance of TCP in this environment. We propose to study two different ways of maintaining TCP connections:

a) End to end connections, from ground user to Internet server. We will evaluate different TCP protocol choices including the legacy TCP New Reno and the newly proposed TCP Westwood [10][12].
b) Proxy server on board of the HAPS/UAV. The idea is to split the TCP connection on the HAPS/UAV and thus reduce the problem into two more tractable subproblems, i.e., a very lossy link with short

propagation delay; and a more reliable (or at least, more predictable) link with very large propagation delay. In this case, different TCP "flavors" may be needed for the differing links characteristics.

Previous studies of TCP connections on mixed wired and wireless paths with 802.11 access have uncovered several pathologies in terms of unfairness and capture. We demonstrate that these problems increase when the satellite replaces the wired segment.

We approach the performance evaluation of TCP (with and without proxy) in various traffic scenarios, with multiple TCP connections (intracell and Internet bound) and in the presence of competing UDP traffic (i.e. video streaming, video conference). In addition, the results could be extended to a system with multiple HAPS/UAVs in the sky to provide more extensive coverage. This latter scenario is clearly much more complex as also introduces the possibility of HAPS/UAV to HAPS/UAV communications (for example, on a separate radio). Moreover, users in the "urban canyon" can handoff to another HAPS/UAV if the first HAPS/UAV goes beyond a building. The handoff must be smooth in order to prevent, for example, disrupting the downloading of a music file. In this paper we approach a simple, representative network scenarios (single HAP/UAV) in which we will test the various TCP options.

2 System architecture

We considered an urban scenario with mobile users (pedestrians and cars) connected by a very efficient communication infrastructure comprising the cellular system as well as a network of Hot Spots placed in strategic locations (busy street crossings, tall buildings, parks, etc). Users access the network for both voice and data services. In fact, the data services (mainly, access to the Internet from mobile users) will see a dramatic growth in the next few years, owing to the introduction of new mobile services such as location based resource discovery (e.g., nearest drugstore), navigation support, web access etc. In this environment that is becoming increasingly dependent on communications, imagine an emergency situation when power goes out and all the Hot Spots and Cellular Base Stations shut off. Communications come to a standstill until power and telecommunication systems are restored. Yet, this is the time when communications are most needed to control vehicular traffic and to allow users to "navigate" their way out of the traffic congestion. At the same time repair crews, police and medical teams need efficient communications to coordinate their work. A similar emergency scenario in an urban area occurs when there is a chemical, nuclear disaster caused by human error, plant break down, act of war, or terrorist attack. Again in such situations the communication infrastructure has been impaired while the need for efficient communications remains critical.

In the depicted scenario it is very cost effective and easy to deploy in a short time a system composed of several HAPS/UAVs (Unmanned Airborne Vehicles) to establish an emergency telecommunication infrastructure. The HAPS/UAV may fly through the "urban canyons" acting as "repeaters". Some of the HAPS/UAVs can be connected to a GEO satellite as depicted in Figure 1.

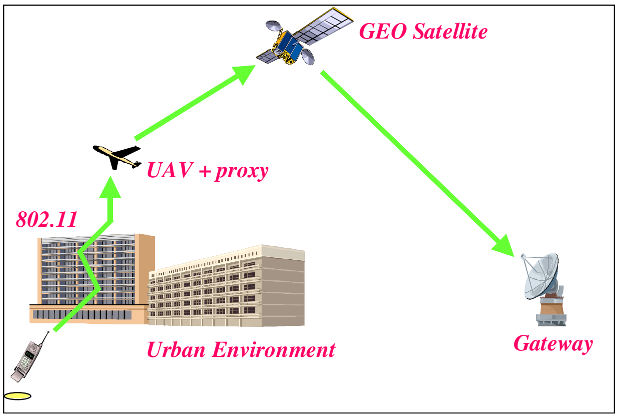

Figure 1: Scenario

The mobile users on the ground can use HAPS/UAVs to communicate with each other and to access the Internet via Satellite. This two level "satellite empowered" architecture allows combining the advantages of very small user terminal technology on the mobiles, capable of handling high data rates, with the ability to establish very long range connections thus greatly enlarging the usual limited coverage of the HAPS/UAV network. In addition, the presence of several flying units allows exploitation of path diversity, extremely useful for improving availability especially in an urban environment. The support of HAPS/UAVs equipped with satellite terminals might in fact be irreplaceable in this case. The HAPS/UAVs, being unmanned, can be flown in areas dangerous to humans, say chemical spills or nuclear attack. They can be deployed very rapidly, thus providing relief within minutes of the accident. Once in place, the HAPS/UAV will act like a Hot Spot to the customers on the ground. Thus, the access protocol will be 802.11, compatible with existing Hot Spot environments. The HAPS/UAV will support intra-cell communications among the users in the cell it covers, as well as Internet connectivity. A point-to-point satellite link will connect the HAPS/UAV to a remote ground station and to the Internet.

For the Internet, highly efficient algorithms must be implemented in order to guarantee large bandwidth access. The following subsections include a more detailed description of the well-assessed TCP Westwood algorithm and a well-known PEP technique called "Splitting", having both already demonstrated significant improvements in TCP performance.

2.1 TCP Westwood

Carefully tuning TCP parameters, including the size of receive buffers (i.e., the advertised window) and the granularity of timers improves performance in some cases. Unfortunately, tuning often fails under conditions of both high bandwidths and large delays; addressing such cases requires a different type of approach. One such class of approaches involves changes to the TCP protocol mechanisms. Here, modifications change the basic error-control and congestion-control strategies for improved performance. Along these lines, UCLA has developed a modification to the Fast Recovery algorithm, TCP Westwood, involving only modifications to the TCP sender[10]. A TCP Westwood sender continuously monitors the effective rate of its connection by analyzing the time between the arrivals of TCP acknowledgments. When this estimation falls below the current transmission rate as a result of packets lost at the bottleneck link, the Westwood sender corrects to match the estimated rate by adjusting its window, and thus eliminates losses from congestion. Using estimated bandwidth instead of packet loss feedback allows Westwood to more efficiently utilize networks with high-bandwidth and high-delay.

2.2 Splitting

Another class of approaches involves additional or enhanced network infrastructure. In this case, intermediaries perform processing on behalf of TCP endpoints to the greater benefit of performance. This basic idea generalizes to the so-called “Performance Enhancing Proxy” or PEP [11]. Of the many PEP schemes, one involves segmenting, or “splitting” the TCP connection into segments. Splitting makes use of TCP gateways that maintain multiple TCP connections with both other gateways and end users. In fact between gateways, splitting may use a specialized or optimized transport protocol.

Many of the same arguments for splitting on-board satellites apply equally to HAPS/UAVs [12]. On-board splitting can provide disparate terminals to communicate through the forwarding agent, that is, it supports TCP terminals without requiring uniform end-to-end TCP. Moreover, some hops may use multicast, and thus more effectively exploit the broadcast nature of wireless transmission while still supporting TCP endpoints. An on-board transport agent also provides more rapid recovery from errors and improves the overall robustness of the end-to-end connection when several links suffer from shadowing or high error-rates. Finally, in contrast with satellites, HAPS/UAVs may be more easily tested and upgraded, thereby lessoning the risk of adding the complexity of the on-board proxy TCP.

3 Simulation scenario

NS2 is a widely adopted simulator for network scenarios [18]. We have chosen to use this platform due to the reliability of its outcomes and the validity of its models, especially in new transport protocols investigation. In order to run our tests we have enhanced version 2.1b8a of this software with some new modules. In particular, we have added the code to simulate the behavior of TCP Westwood ABSE and the splitting scheme at the HAPS/UAV.

Figure 2 represents the topology utilized for the simulations; it also provides some information regarding simulation parameters. Each of the circles corresponds to one of the actors in the proposed scenario, specifically:

- W: wireless device in the urban area
- U: HAPS/UAV (eventually with proxy on board)
- S: GEO satellite
- G: gateway on the ground

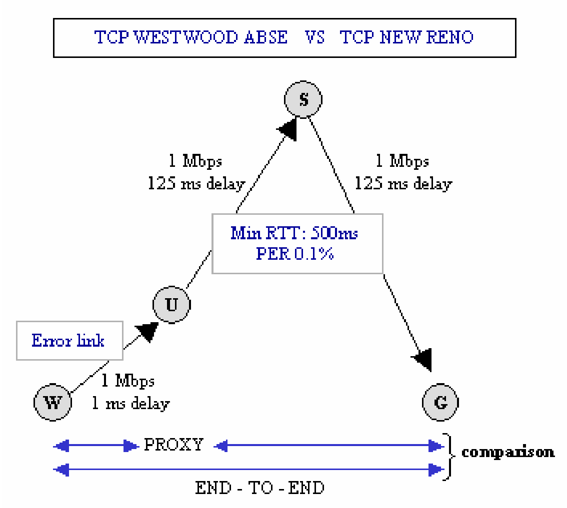

Figure 2: Simulation configuration

The propagation delay between W and U is very short due to the flying altitude of the HAPS/UAV. A typical GEO satellite delay, instead, is used between U and S, and between S and G. The wireless nature of every edge in the scenario requires the introduction of error losses on the links [15][16][17]; in particular, we have set a constant PER (Packet Error Rate) of 0.1% on the two satellite links, from U to S and from S to G. In order to test the performance under a more comprehensive set of possible urban conditions, different values of PER have been applied on the short wireless link between W and U. The bandwidth on the whole path is 1Mbps, the size of the packets is 1500 Bytes, the buffer available between W and U is 50 packets and the cache on the proxy, when splitting mechanism is enabled, amounts to 200 packets.

In our simulations, each FTP/TCP flow lasts for 230 seconds. Simulations are run using different combinations of transport protocol, various PER on the shortest wireless link, presence or absence of a proxy on the HAPS/UAV and alternate direction of the data flow, specifically:

- transport protocol:
  - TCP New Reno, TCP Westwood
- PER on the link between W and U:
  - 0.1%, 0.5%, 1.0%
- proxy on board:
  - split enabled, split disabled
- traffic direction:
  - from W to G, from G to W

Every run has been replicated twenty times changing the seed value of the random generator. The final outcomes have been averaged in order to obtain the number of packets sent in 230 seconds, the consequent throughput achieved and the time needed to transmit a file of 5MB.

4 Results

Simulations represented in Figure 3 consider the time required to transmit a 5 MByte file from W to G and show a considerable advantage obtained over lossy links implementing TCP Westwood replacing the traditional TCP New Reno. In our configuration, in fact, the former transport protocol requires only from 65.97% (with 0.1% PER) to 46.13% (with 1% PER) of the average time needed by the latter one. It is also evident that the adoption of a proxy in the HAPS/UAV that splits the connection provides an advantage, allowing TCP New Reno to achieve the same, or even slightly better, performance than does an end-to-end TCP Westwood.

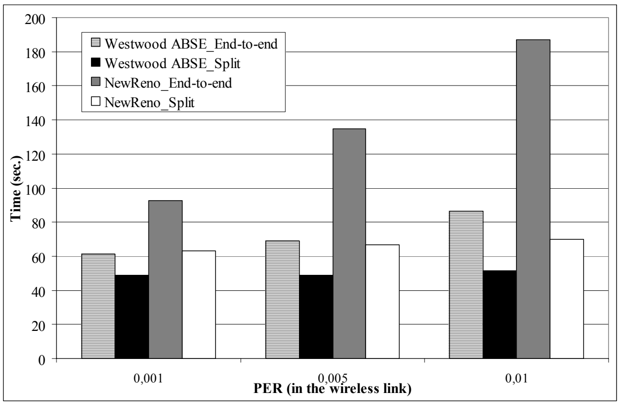

Figure 3: Time to transmit a 5 MByte file from W to G

Comparing the two transmission protocols in the case in which both use the proxy in the HAPS/UAV, we observe again a sensible reduction of the transmission time if TCP Westwood is employed. If compared to TCP New Reno, in fact, TCP Westwood takes less, needing from 77.50% (with 0.001 PER) to 73.08% (with 0.005 PER). This demonstrates that TCP Westwood generally outperforms traditional transport protocols on wireless links involving long satellite paths. It also shows that using a combination of both TCP Westwood and a splitting scheme achieves the best results. However, even singularly applied, each technique leads to a sensible improvement when compared with the traditional state of the art. Finally, it is worth noticing the ability of the on-board proxy to hide the frequent losses of the shortest wireless link from the rest of the connection. In fact, the total time required by either protocol to download a 5Mb file remains almost the same for all the three different PER tested.

In Figure 4 we compare the average throughput achieved for different combinations of transport protocol, eventual utilization of the split mechanism and various PER in the shortest wireless link. In particular, for each configuration we have averaged the number of bytes sent in 230 seconds on a set of 20 simulations to obtain the reported throughput. Again, TCP Westwood coupled with a proxy in the HAPS/UAV gets the best performance, with an average throughput that goes from 84.14% of the available bandwidth (with a PER of 1%) to 86.1% (with a PER of 0.1%). The ability of the splitting mechanism to hide the frequent errors on the shortest wireless link from the rest of the connection is confirmed even in this case. The average throughput achieved, in fact, remains almost constant through the various PER tested, independently of transport protocol employed.

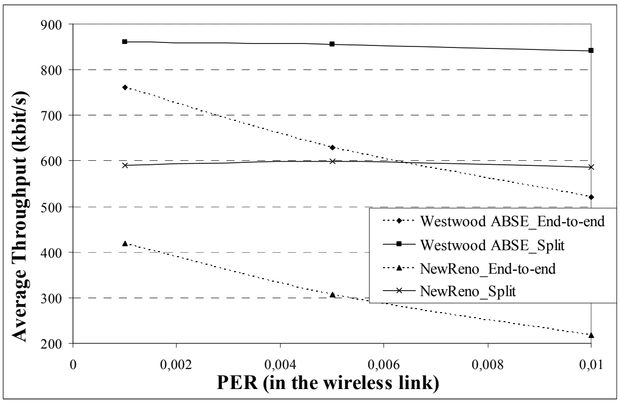

Figure 4: Average throughput over a 230 sec transmission

For the sake of completeness, a set of simulations has also been performed which consider the reverse data flow: from G to W. Perhaps easily forseen, the outcomes closely resemble the previous results. In fact, even in this case performance increases as a result of TCP Westwood's ability to deal with wireless links, while the splitting scheme again protects the whole connection from the frequent errors present on the edge between W and U. The average times required to transmit a 5MB file from G to W are shown in Figure 5, while Figure 6 illustrates the average throughput attained on 230 seconds of simulation along the same path.

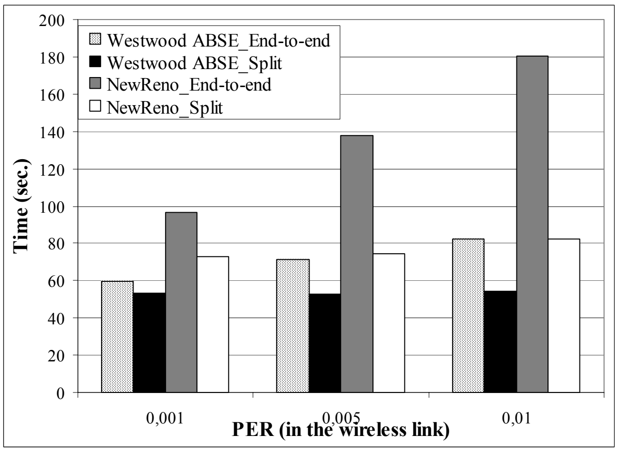

Figure 5: Time to transmit a 5MByte file from G to W

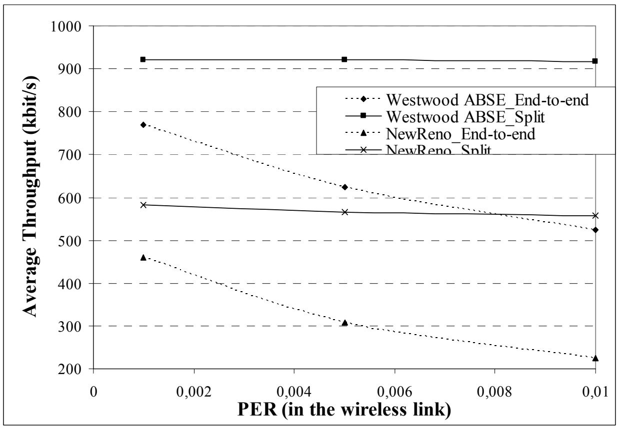

Figure 6: Average throughput over a 230 sec transmission

5 Conclusions

The characterisation of innovative system architecture to efficiently approach emergency situations when the telecommunication infrastructures may not be available has been addressed. The combined use of HAPS/UAV and a satellite has been identified as the most efficient architecture to rapidly provide service not renouncing to long range connection. In order to identify the most efficient solution for TCP based applications the use of different TCP protocols and the TCP split technique have simulated. The combined use of TCP Westwood and the TCP split has shown the best performance.

References

[1] T. C. Tozer and D. Grace, High-altitude platforms for wireless communications, Electronics & Communication Engineering Journal, June 2001, pp. 127-137.

[2] D. Avagnina, F. Dovis, A. Ghiglione, P. Mulassano, Wireless networks based on high-altitude platforms for the provision of integrated navigation/communication services, IEEE Communications Magazine , Volume: 40 Issue: 2 , Feb 2002 Page(s): 119 -125

[3] Lutz, D. Cygan, M. Dippold, F. Dolainsky, W. Papke, "The Land Mobile Satellite Channel - Recording, Statistics and Channel Model", IEEE Trans. on Vehic. Techn., Vol. VT - 40, May 1991.

[4] E. Corazza, F. Vatalaro, "A Statistical Model for Land Mobile Satellite Channels and its Application to Nongeostationary Orbit Systems", IEEE Trans. on Vehic. Techn. , pp. 738-741, Vol. VT - 43, Aug. 1994.

[5] E. Lutz, "A Markoff Model for Correlated Land Mobile Satellite Channels", International Journal of Satellite Communications, pp. 333-339, vol. 14, February 1996.

[6] F. P. Fontán, M. A. Vázquez, S. Buonomo, E. Kubista, A. Paraboni, B. Arbesser, B. Baptista, "A Methodology for the Characterisation of Environmental Effects on Global navigation Satellite System (GNSS) Propagation", International Journal of Satellite Communications, pp. 1-22, vol 16, 1998.

[7] F. Mazzenga, F. Vatalaro, "Channel Modelling and Performance Evaluation of EO Systems", AP2000 Davos, Switzerland, April 9-14, 2000.

[8] P. Loreti, M. Luglio, *A Generalized N-State Model to characterize satellite diversity for arbitrary number of satellites in case of uncorrelated channels*, IEEE Communications Letters, Volume: 5, Issue: 11, Nov. 2001, pp. 447 -449.

[9] P. Loreti, M. Luglio, *Satellite Diversity: a Technique to Improve Link Performance and Availability for Multicoverage Constellations*, chapter in P. Stavroulakis (Ed) "3rd Generation Mobile Communication Systems, UMTS and IMT-2000", Springer Verlag, Berlin, 2001.

[10] C. Casetti, M. Gerla, S. Mascolo, M. Y. Sanadidi, and R. Wang, *TCP Westwood: Bandwidth Estimation for Enhanced Transport over Wireless Links*, In Proceedings of Mobicom 2001, Rome, Italy, Jul. 2001.

[11] J. Border, M. Kojo, J. Griner, G. Montenegro and Z. Shelby, "Performance Enhancing Proxies intended to mitigate link-related degradations", RFC 3135, June 2001.

[12] J. Stepanek, Ashu Razdan, Alok Nandan, M. Gerla, M. Luglio, *The Use of a Proxy on Board the Satellite to Improve TCP Performance*, IEEE Global Telecommunications Conference, 2002, GLOBECOM '02, Vol. 3, Nov. 17-21, 2002, pp. 2950–2954.

[13] R. Càceres, L. Iftode, *The Effects of Mobility on Reliable Transport Protocols*, 14th International Conference on Distributed Computing Systems, pp. 12 - 20, June 1994.

[14] H. Balakrishnan, V. N. Padmanabhan, S. Sehan, and R. H. Katz, "A comparison of mechanism for improving TCP performance over wireless links", IEEE/ACM Trans. Networking, vol. 5, no. 6, pp. 756 - 769, December 1997.

[15] P. Sinha, N. Venkitaraman, R. Sivakumar, V. Bharghavan, *WTCP: A Reliable Transport Protocol for Wireless Wide-Area Networks*, ACM Mobicom '99, August 1999.

[16] http://www.isi.edu/nsnam/ns/

[17] R. Wang, M. Valla, M.Y. Sanadidi, and M. Gerla, *Adaptive Bandwidth Share Estimation in TCP Westwood*, In Proc. GLOBECOM'02, November 2002.